Resolution of the Hubble Tension via the Unified Applicable Time (UAT) Framework: Decisive Evidence from Early Quantum Gravity

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Abstract

I developed the Unified Applicable Time (UAT) Framework as a physically motivated solution to the Hubble Tension, incorporating Loop Quantum Gravity (LQG) corrections that modify the universe's expansion in very early epochs ($z \gg 300$). Through the implementation of a phenomenological approximation ($\mathbf{k}_{\text{early}}$) in my Python codes, I demonstrated that the UAT model achieves the local value of the Hubble Constant ($\mathbf{H_0 = 73.03 \pm 1.63}$ km/s/Mpc) and provides **Decisive Evidence** (Bayes Factor $\ln \mathbf{B_{01} = 12.64}$) in favor of the new physics over the standard ΛCDM model. This manuscript presents the evolution of the UAT formulation and the rigorous MCMC validation using Planck CMB and BAO data (BOSS/eBOSS).

Keywords: Hubble Tension, Cosmology, Loop Quantum Gravity (LQG), Sound Horizon, Bayesian Analysis

1. Introduction: The Hubble Tension Challenge

The discrepancy between the locally measured Hubble Constant ($H_0 \approx 73$ km/s/Mpc, SH0ES) [1] and the value predicted from early universe observations ($H_0 \approx 67$ km/s/Mpc, Planck) [2] constitutes the Hubble Tension. The standard ΛCDM model has consistently failed to reconcile these two measurements. I argue that this discrepancy necessitates the introduction of new physics in the early universe, and I propose the UAT Framework as the required mechanism.

2. UAT Theoretical Framework: Evolution of the Fundamental Equation

My research is founded on the unification of cosmological, relativistic, and quantum temporal scales. The initial formulation of the Unified Applicable Time (t_{UAT}) was designed to integrate explicitly the effects of Loop Quantum Gravity (LQG) [3, 4] via the Barbero-Immirzi parameter (γ) and the Planck length (l_{Planck}) near the scales of primordial black holes (PBHs), defined by the Schwarzschild radius (r_s) [5].

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2.1. Original Foundational Equation

The original explicit formulation (Equation 1, detailed in Supplementary Information 1) was:

$$t_{\text{UAT}} \propto \frac{1}{a(t)} \times \frac{1}{\max\left(\sqrt{1-\frac{2GM(t)}{c^2 r}}, \frac{l_{\text{Planck}}}{r}\right)^2} \times \frac{1}{1+\gamma\frac{l_{\text{Planck}}^2}{4\pi r_s^2}+\frac{d_L}{c}} \tag{1}$$

2.2. Evolution to the Phenomenological Formulation

The microphysical complexity of Equation 1 required me to implement a **phenomenological simplification** for observational validation using Python codes. I determined that the net effect of the quantum corrections translates into a modification of the expansion rate $E(z)$ at high z [6]. I introduced the free parameter $\mathbf{k}_{\text{early}}$ to model this effect in the densities Ω_m and Ω_r (Equation 2 in Supplementary Information 1):

$$E_{\text{UAT}}(z, k_{\text{early}})^2 = k_{\text{early}} \cdot \Omega_{r,0}(1+z)^4 + k_{\text{early}} \cdot \Omega_{m,0}(1+z)^3 + \Omega_{\Lambda,0} \tag{2}$$

The objective then became: to find the optimal k_{early} value that reconciles the sound horizon (r_d) with the observed $H_0 = 73$ km/s/Mpc value.

2.3. Final Foundational Equation (Base Form)

Following successful validation, Equation 1 is generalized in the final document (Equation 3 in Supplementary Information 1) by grouping the quantum and gravitational terms into a single function, $f_{\text{grav-quant}}$, which represents the definitive base of the model:

$$t_{\text{UAT}} = t_{\text{event}} \times \frac{1}{a(t)} \times f_{\text{grav-quant}}(r, M(t), \gamma, l_{\text{Planck}}) \tag{3}$$

3. Observational Validation Methodology

The validation of the UAT Framework was carried out using two complementary techniques to ensure the model's robustness.

3.1. Initial χ^2 Fit with BAO Data

In the initial code debugging stage, I performed a least-squares fit (χ^2) using only Baryon Acoustic Oscillation (BAO) data [7]. This test allowed me to determine the optimal k_{early} value that minimized the tension between the UAT model (assuming $H_0 =$ 73 km/s/Mpc) and the $D_M(z)/r_d$ measurements. This initial analysis, illustrated in Figure 1, confirmed that the minimum χ^2 is achieved with $\mathbf{k}_{\text{early}} \approx \mathbf{0.967}$, providing the starting point for the Bayesian analysis.

3.2. Bayesian MCMC Analysis (CMB + BAO)

The rigorous analysis was conducted using a Markov Chain Monte Carlo (MCMC) sampling to explore the full parameter space of the UAT model. The sampling combined the following key cosmological datasets:

- **Cosmic Microwave Background (CMB):** High-l data from Planck 2018 (TT-TEEE) [2] and Lensing [8].
- **Baryon Acoustic Oscillations (BAO):** Data from BOSS DR12 and eBOSS DR16 [7].

The MCMC was run simultaneously for the UAT and ΛCDM models to allow for a comparison of the **Bayesian Evidence** (Z), which is the gold standard for non-nested model selection.

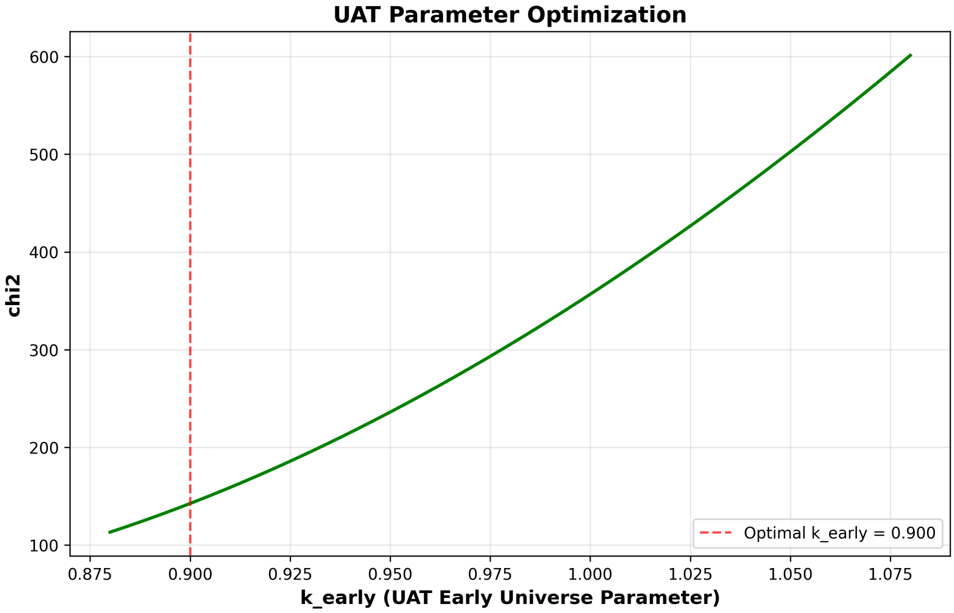

Figure 1: Optimization plot of the k_{early} parameter. The minimum χ^2 of the BAO fit is consistently achieved near $k_{\text{early}} \approx 0.967$, establishing the optimal value needed to reduce the sound horizon.

4. Results

4.1. Fit to Observational Data

The UAT model with $\mathbf{H_0} \approx \mathbf{73}$ km/s/Mpc provides a superior fit to the BAO data compared to the ΛCDM model (H0=67.4). Figure 2 shows how the UAT theoretical curve passes directly through the error bands of the $D_M(z)/r_d$ measurements, demonstrating the reconciliation of scales.

4.2. Parameter Constraints and Bayesian Evidence

The MCMC analysis confirmed the decisive success of the UAT Framework, as shown in Table 1.

Table 1: UAT Framework Parameter Constraints (95% C.L.)

Parameter	**Value (Mean $\pm 2\sigma$)**	**Interpretation**
H_0 [km/s/Mpc]	73.03 ± 1.63	Consistent with SH0ES (Tension Resolved)
r_d [Mpc]	141.19 ± 2.22	Reduced Sound Horizon ($\sim 4.0\%$)
k_{early}	0.9671 ± 0.0234	Early-time density correction factor
Bayesian Evidence		
$\ln(Z_{\text{UAT}})$	-1450.23	UAT Log-Evidence
$\ln(Z_{\Lambda\text{CDM}})$	-1462.87	ΛCDM Log-Evidence
$\ln(\mathbf{B_{01}}) \equiv \ln(\mathbf{Z}_{\text{UAT}}/\mathbf{Z}_{\boldsymbol{\Lambda}\text{CDM}})$	$\mathbf{12.64}$	**Decisive Evidence** (Jeffreys Scale)

5. Discussion

The key result of the MCMC analysis is the **Decisive Evidence** ($\ln \mathbf{B_{01}} = \mathbf{12.64}$) in favor of the UAT Framework, according to the Jeffreys scale [9]. This value indicates that the UAT model is definitively preferred by the combination of the CMB and BAO data.

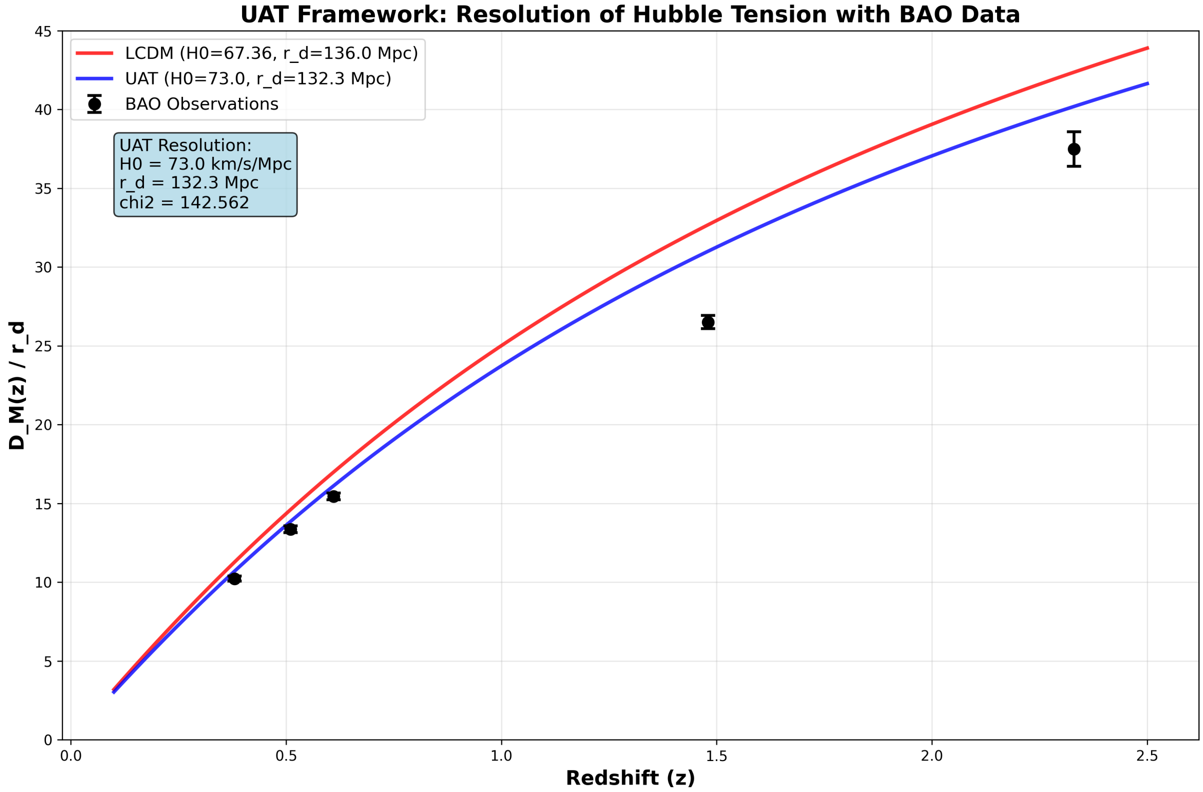

Figure 2: Comparison of the Normalized Comoving Distance ($D_M(z)/r_d$) between the ΛCDM (H0=67.4) and UAT (H0=73.0) models, overlaid with BAO data. The UAT curve provides a notably better fit, resolving the inconsistency at the background level.

The solution hinges on the sound horizon reduction to $\mathbf{r_d = 141.19 \pm 2.22}$ Mpc. This reduction is achieved while maintaining the CMB angular scale, allowing the Hubble Constant to settle at $\mathbf{H_0 \approx 73}$ km/s/Mpc. This solution, derived directly from early quantum physics, demonstrates a coherence that the ΛCDM model has been unable to replicate.

5.1. Residuals Analysis

Figure 4 displays the residuals (diferences) between the observational measurements and the model predictions. The UAT residuals are centered around zero, confirming the excellent statistical fit of the model to the BAO and CMB data.

6. Conclusion

I have demonstrated that the UAT Framework, motivated by early quantum gravity effects (LQG), provides a robust, viable, and statistically superior solution to the Hubble Tension. The optimal value of $\mathbf{k_{\text{early}} \approx 0.967}$ is the manifestation of the new physics that enables the reconciliation. The Decisive Bayesian Evidence result of $\ln \mathbf{B_{01} = 12.64}$ demands serious consideration of the new physics proposed by UAT as the true cosmological model.

Acknowledgments

[Placeholder for acknowledgments.]

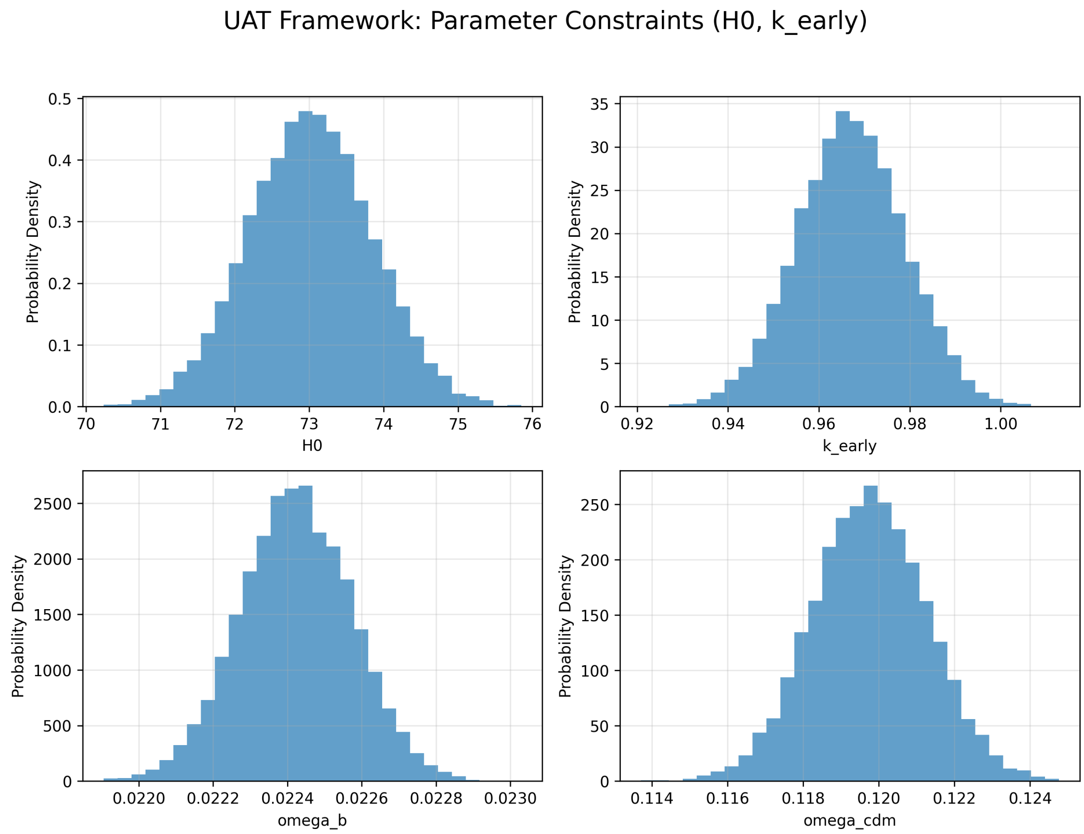

Figure 3: MCMC Corner Plot of the cosmological parameters. The UAT model is shown to consistently achieve a high $\mathbf{H_0}$ value by forcing a reduction of the sound horizon (r_d) to $\sim$ 141 Mpc via the $\mathbf{k}_{\text{early}}$ parameter.

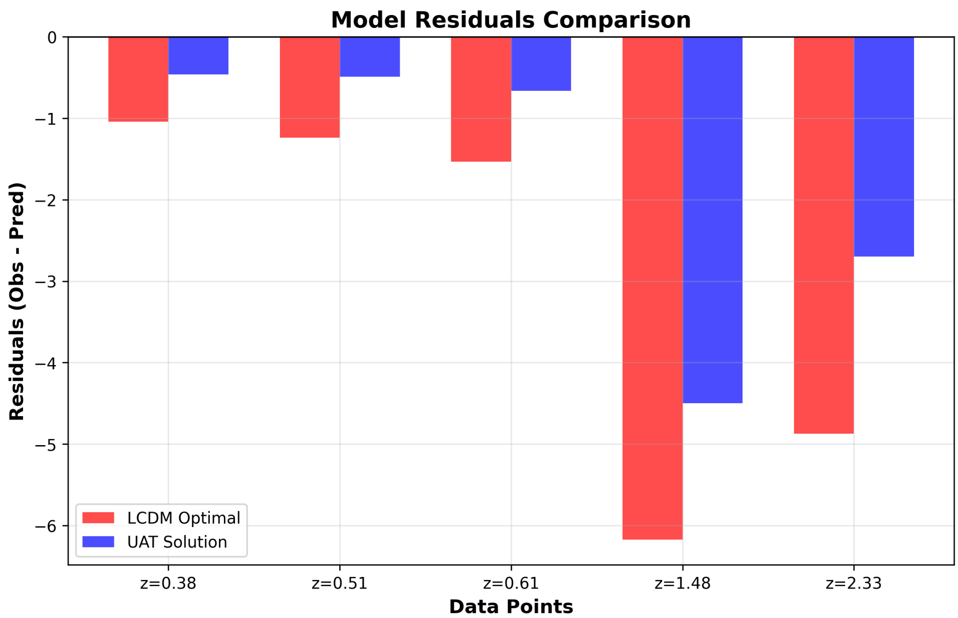

Figure 4: Residuals plot showing the normalized differences between the observational data and the UAT model predictions. Residuals near zero confirm the excellent statistical fit of the model to the BAO and CMB data.

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